Methods for Lightning Detection System Evaluation

Vaisala Thunderstorm

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VAISALA

Performance Measures

Stroke Detection Efficiency

- Fraction (or percentage) of actual CG strokes that were detected by the network

Flash Detection Efficiency

- Fraction (or percentage) of actual flashes that were detected by the network. A flash is detected if one or more strokes are detected.

Location Accuracy

- The error in the position (lat/lon/altitude) provided by the network (expressed as a distance error: RMS or median)

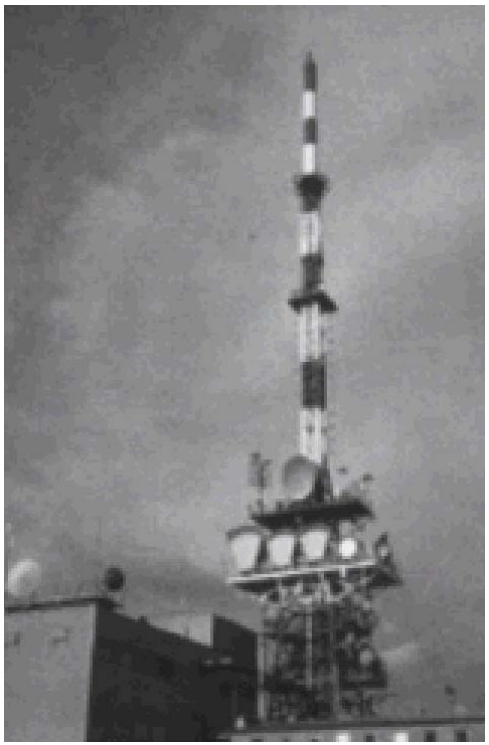
Peak Current Estimation Error

- Fraction (or percentage) error on the magnitude of the peak current estimate provided by the network

Type Classification Error

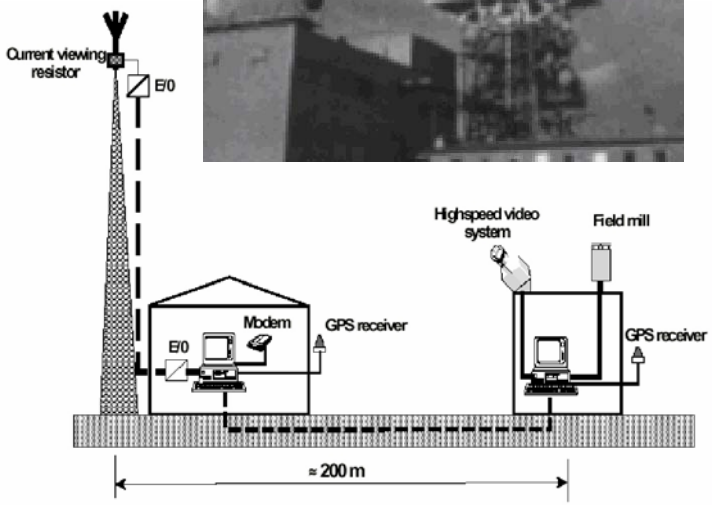
- Fraction (or percentage) of the time that the network incorrectly identified the type of lightning discharge (CG or cloud discharge)

LLS Evaluation Methods – Subsequent Strokes



Instrumented Tower Studies

Gaisberg Tower:
Instrumented TV tower
near Salzburg, Austria



Rocket Triggered Lightning Studies

Camp Blanding RTL site
near Gainesville, Florida

Rocket Triggered Lightning Studies

Strengths:

- **Know precise location**
- **Can directly measure peak current**
- **Usually a "side benefit" of basic research objectives**

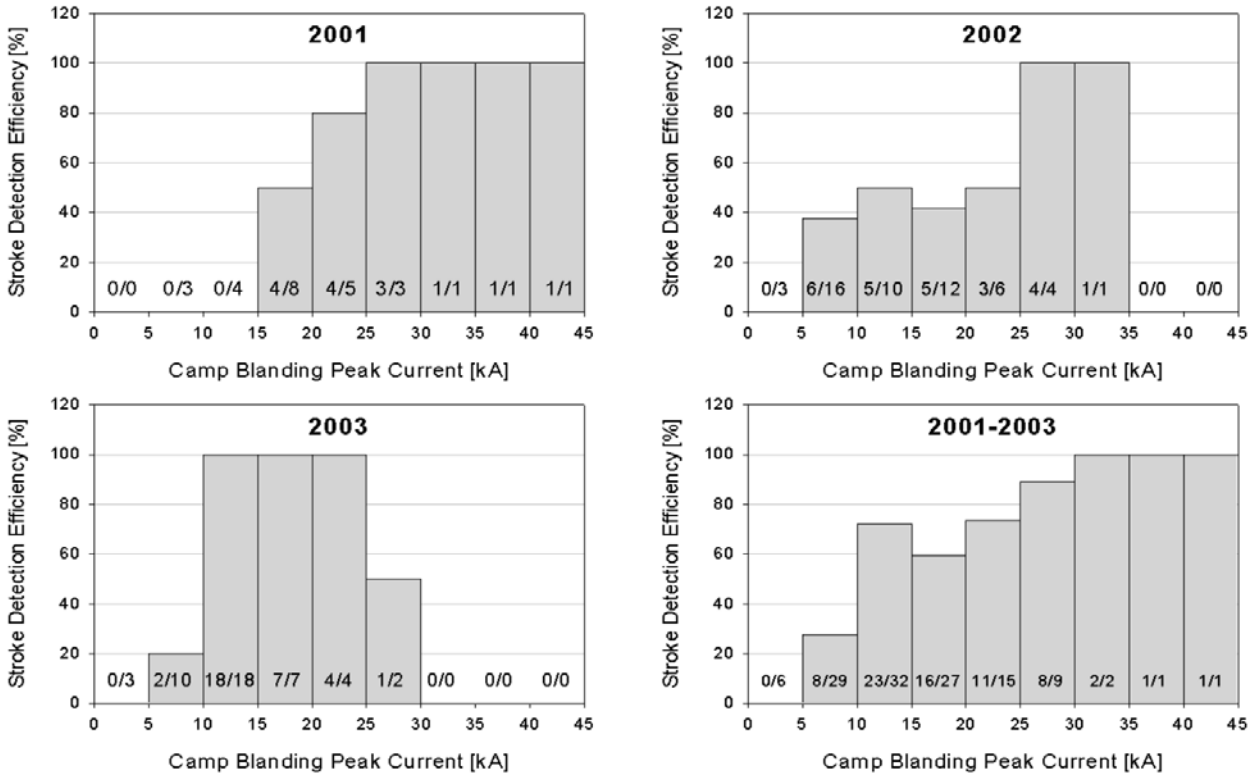
Weaknesses:

- **Can collect a few events per year, depending on GFD**
- **Do not get natural first strokes**
- **Only characterizes performance in one location**

Rocket Triggered Lightning Studies

The following five slides contain example results obtained at the International Center for Lightning research and Testing, at Camb Blanding, Florida (see Jerauld et al., 2004)

RTL Subsequent Stroke Detection Efficiency

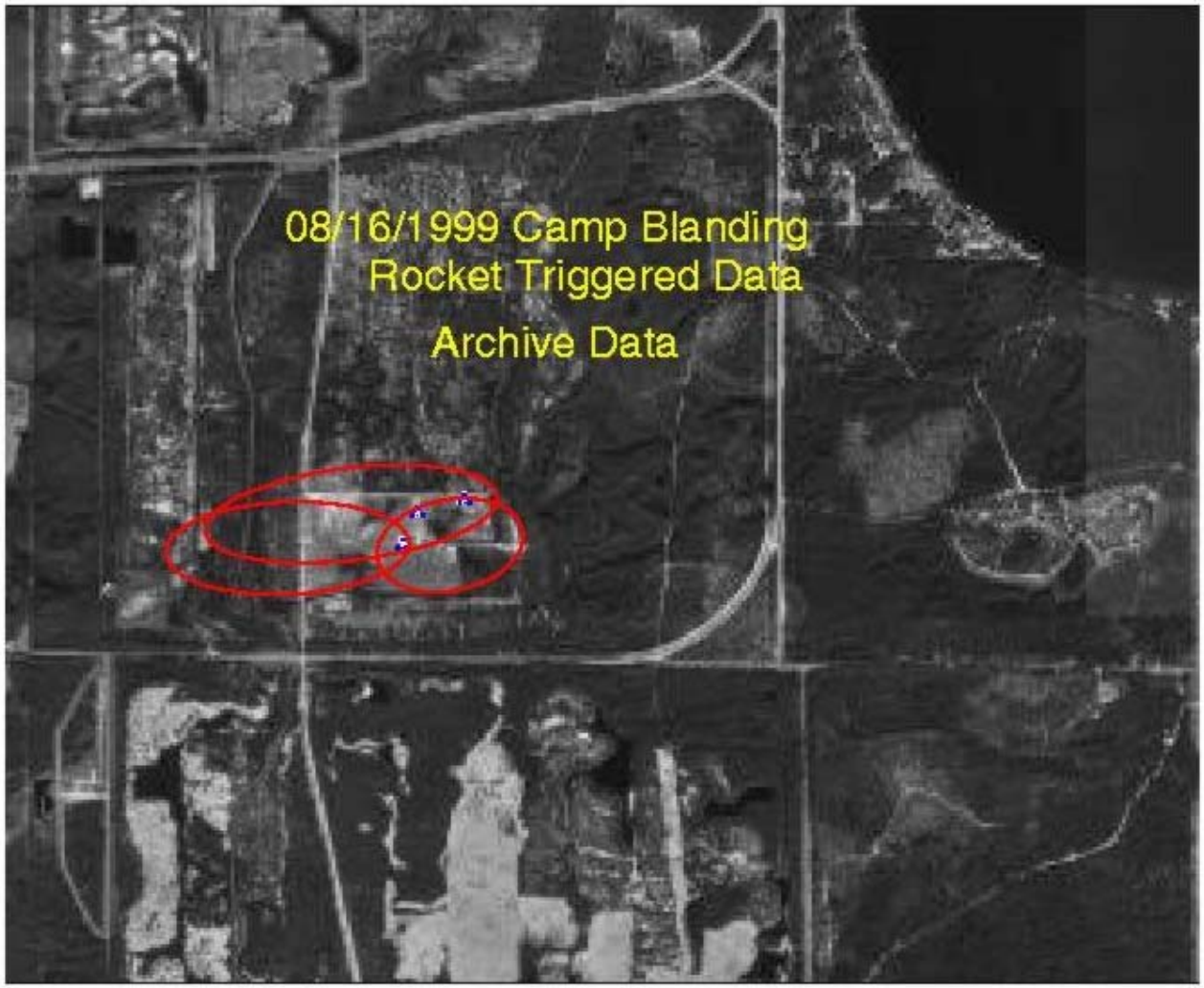


RTL Detection Efficiency Summary

Year	Number of Flashes Triggered	Number of NLDN Detected Flashes	NLDN Flash Detection Efficiency	Number of Strokes	Number of NLDN Detected Strokes	NLDN Stroke Detection Efficiency	NLDN Multiplicity
2001	11	9	82%	33	17	52%	1.89
2002	14	12	86%	77	44	57%	3.67
2003	12	10	83%	49	34	69%	3.40
Combined	37	31	84%	159	95	60%	3.06

Note: The NLDN Flash Detection Efficiency shown here is for “RTL” flashes, which do not contain natural first strokes. Based on these data, estimated “natural” lightning flash detection efficiency exceeds 90% in this area.

RTL Location Accuracy – 50% Error Ellipses



RTL Location Accuracy

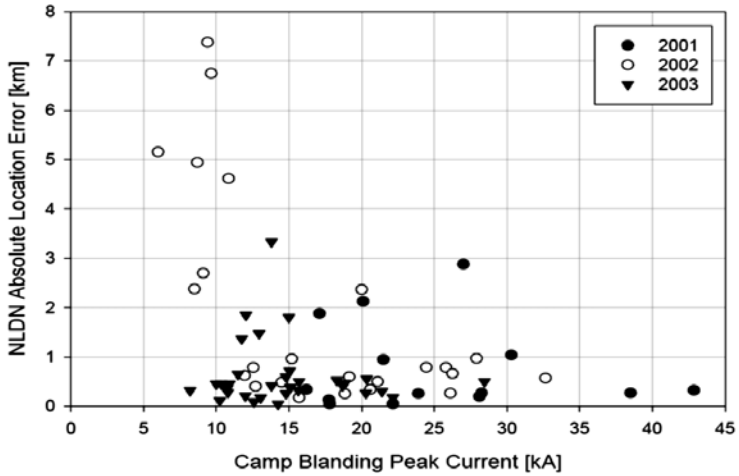


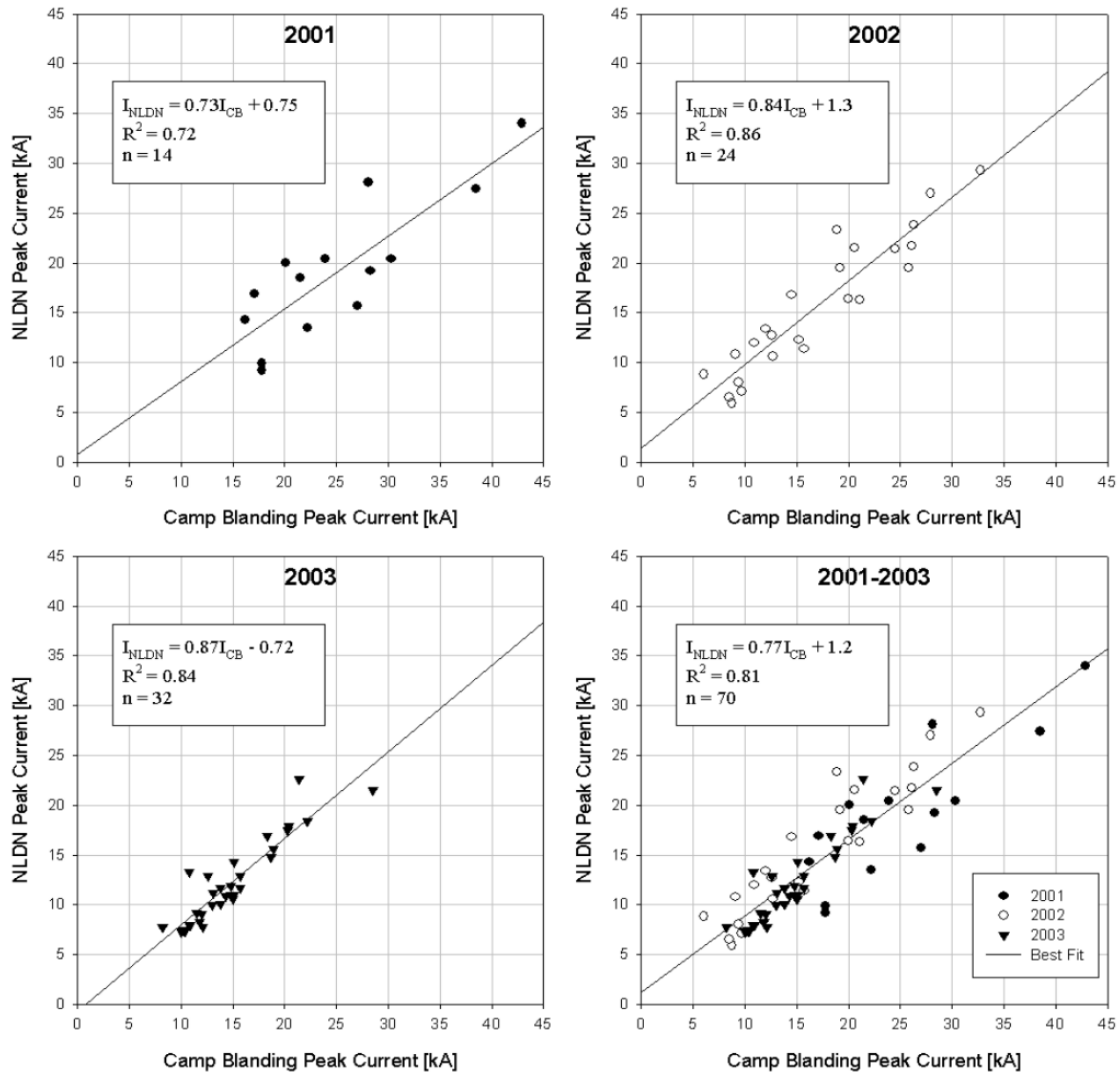
Figure 2b shows the absolute NLDN location error plotted as a function of the ground-truth peak current. This plot contains only the 70 return strokes (in 22 flashes) for which a peak current measurement was obtained. The majority of large (>2 km) location errors occur in the 5-10 kA range during 2002. Also, this plot indicates that return strokes with large location errors mostly had low peak currents.

Location statistics are contained in Table 2. Excluding 2002, the location error means and standard deviations decreased from 2001 to 2003. In 2002, 8 events were detected by only 2 sensors, both of which were south of Camp Blanding. These 2-sensor locations are a result of the low peak current values, coupled with intermittent outages at the LPATS sensor in the Florida panhandle. The replacement of this and other nearby sensors with IMPACT ESP in 2003 eliminated this problem.

	2001	2002	2003	2001-2003
Arithmetic Mean, km	0.66	2.42	0.64	1.47
Standard Deviation, km	0.85	2.75	0.67	2.13
Geometric Mean, km	0.31	1.31	0.44	0.68
Minimum, km	0.05	0.17	0.04	0.04
Maximum, km	2.88	11.00	3.33	11.00
Sample Size	17	44	34	95

RTL Peak Current Estimates

Figure 3 is a plot of the NLDN-estimated peak current plotted versus ground-truth peak current. Note the strong positive linear relationship between the measured and NLDN-estimated peak currents in all three years, although the R^2 value increase in 2002 and 2003. For the combined 3 year data, NLDN peak current estimates are 23% lower than ground truth peak current measurements, thus the correction factor for NLDN peak current is about 1.3.



Instrumented Tower Studies

Strengths:

- **Know precise location**
- **Can directly measure peak current**
- **Requires no "operator interaction"**
- **Usually a "side benefit" of basic research objectives**

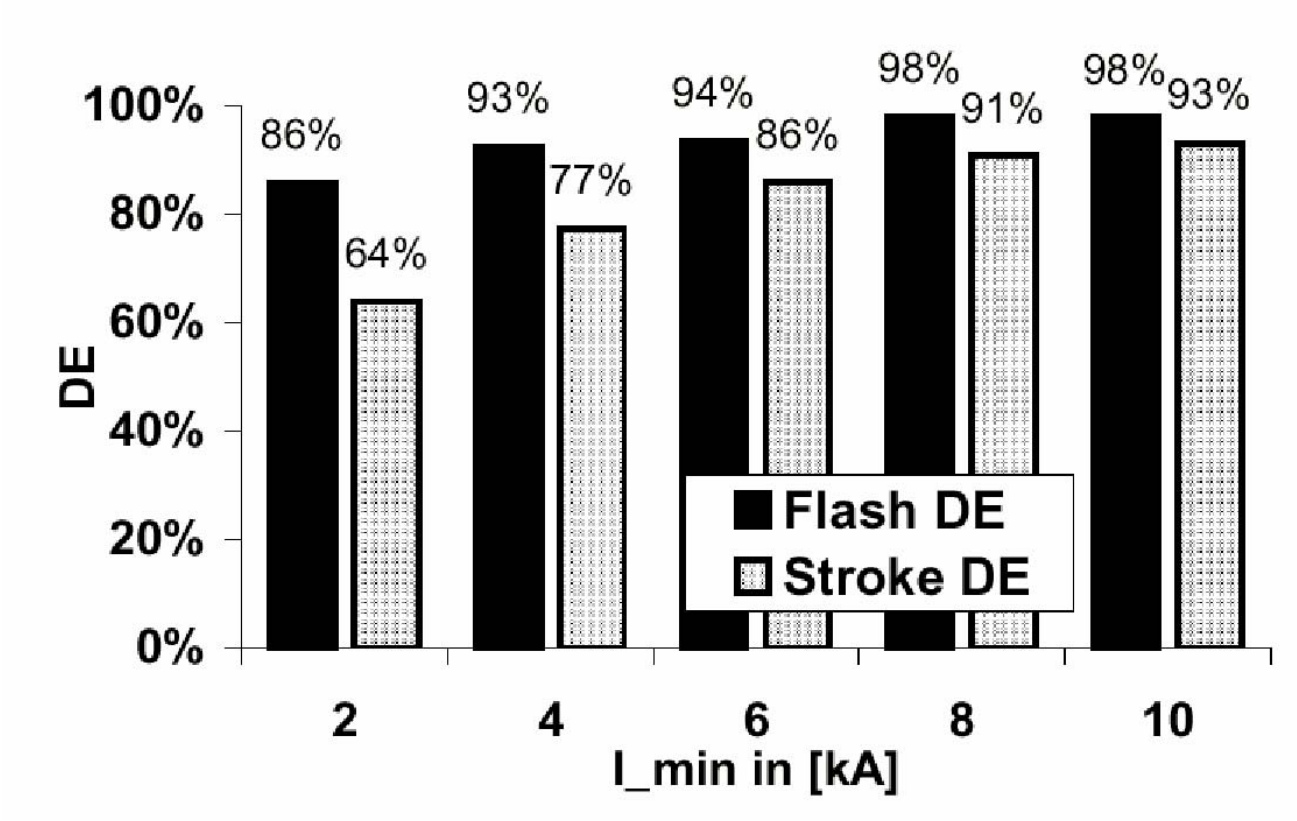
Weaknesses:

- **Can collect a few events per year, depending on GFD**
  - **Usually more than RTL studies**
- **Gets few natural first strokes, depending on height**
- **Only characterizes performance in one location**

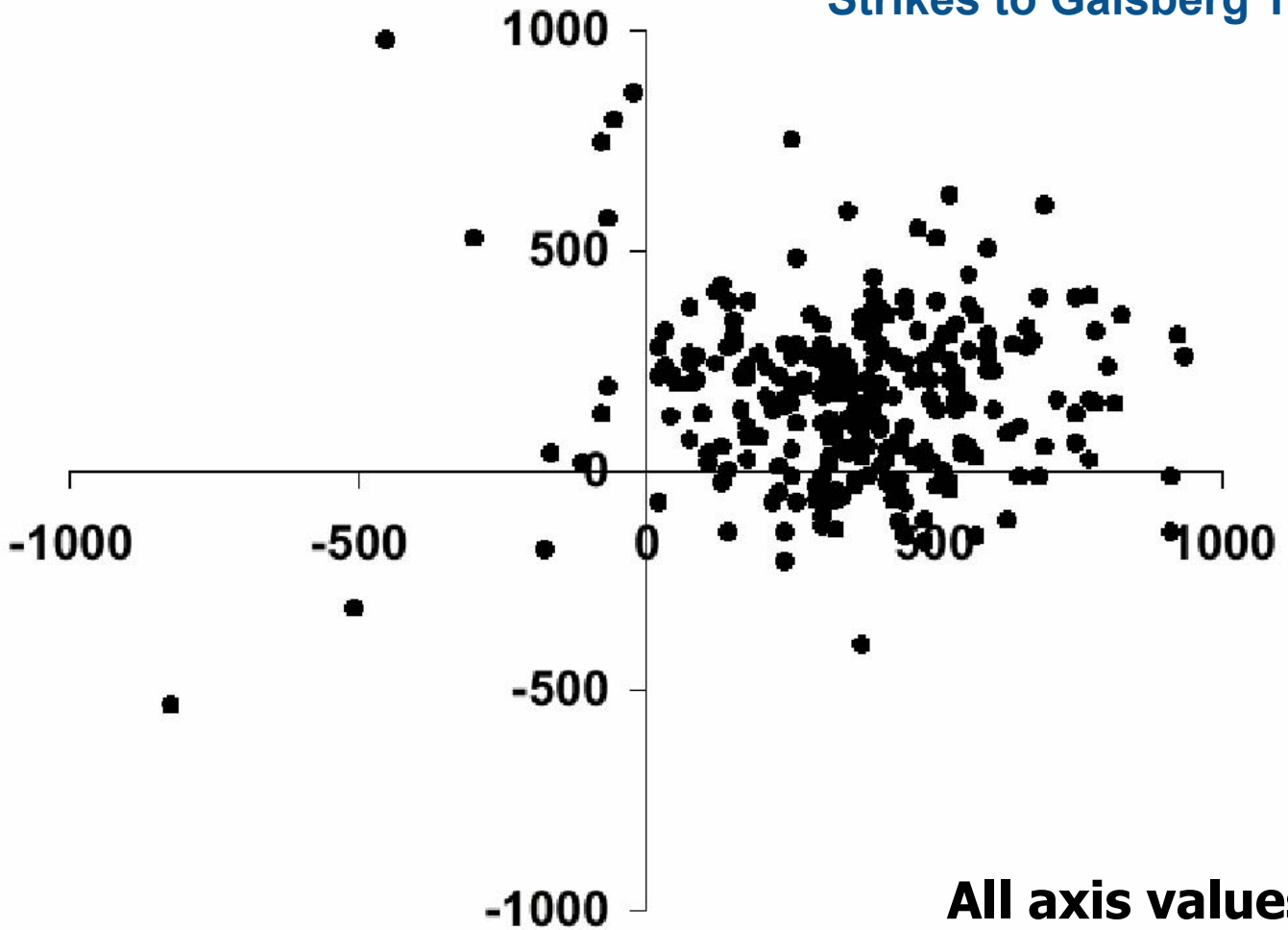
Instrumented Tower Studies

The following four slides contain example results obtained at the Gaisberg tower in Austria (see Diendorfer et al., 2002)

ALDIS DE vs. Peak Current Strikes to Gaisberg Tower during 2000-2001

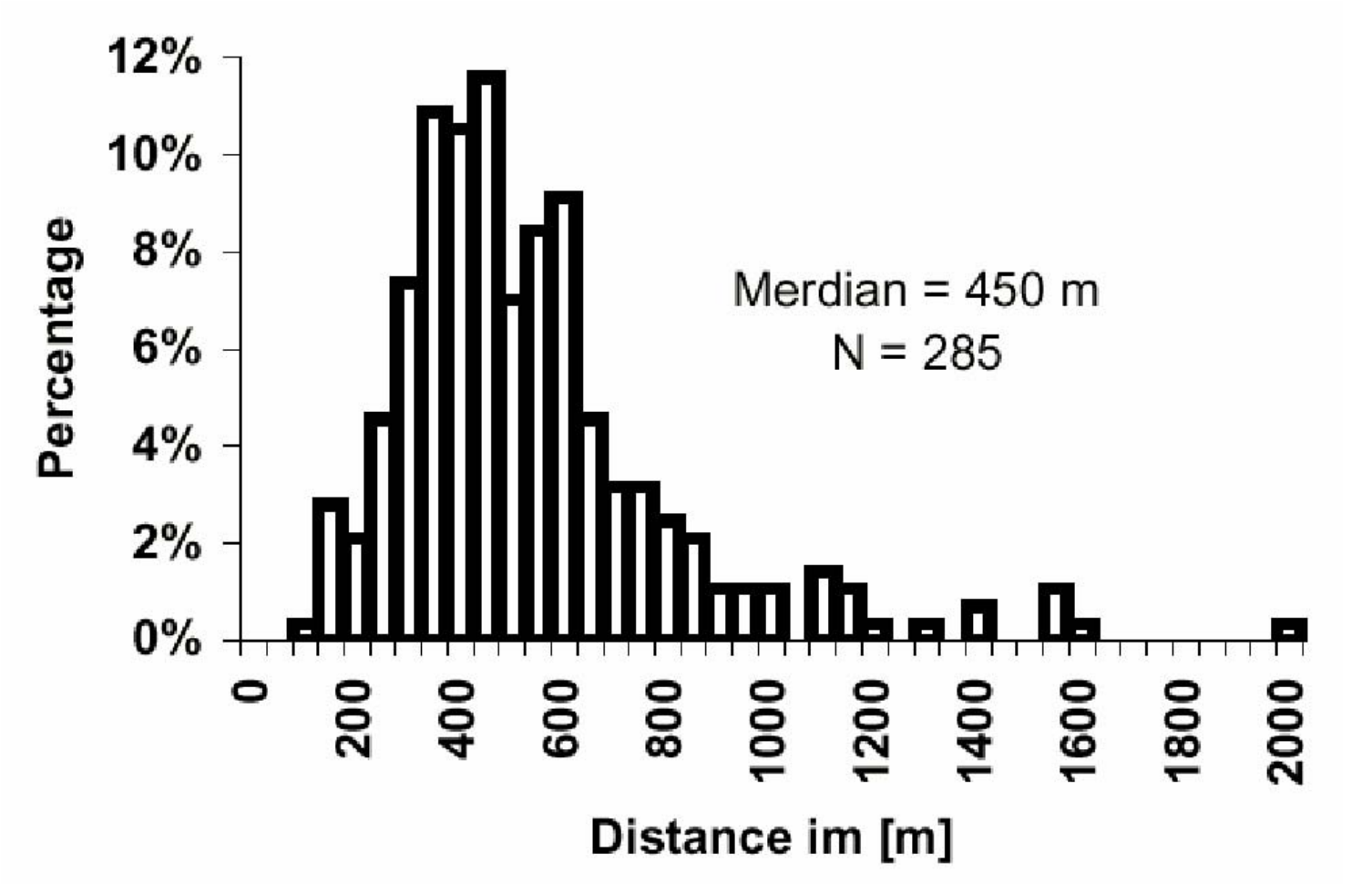


ALDIS Location Accuracy Plot for Strikes to Gaisberg Tower

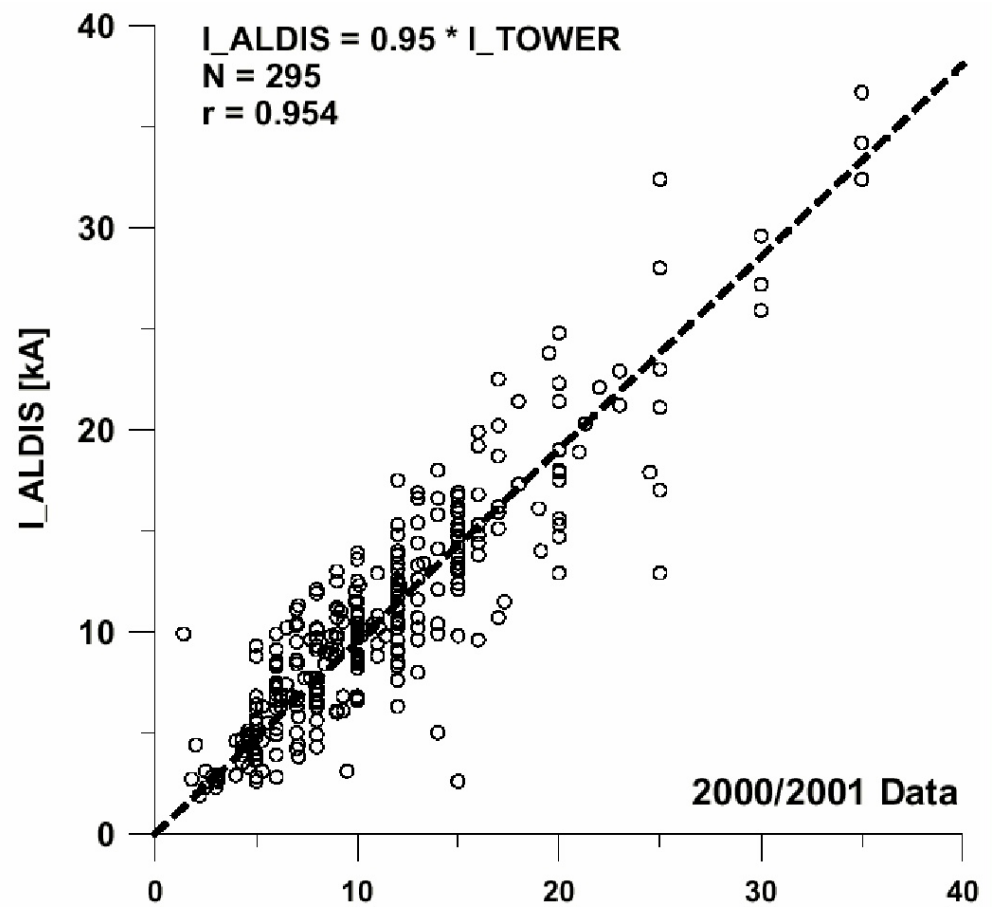


All axis values in meters

ALDIS Location Error Histogram



ALDIS Peak Current verification vs. measurements on Gaisberg Tower

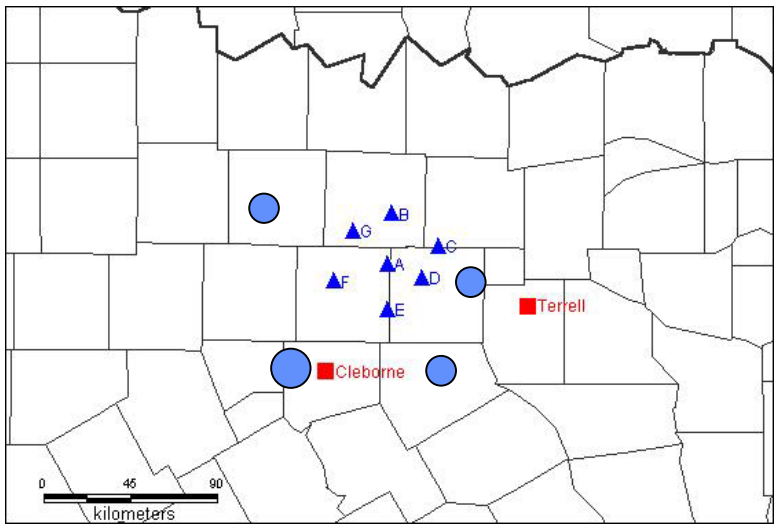


LLS Evaluation Methods – Natural Lightning

Video Camera studies

Field #	1	2	3	4 - 6
Interval	0 – 16 ms	17 – 33 ms	...	50 – 83 ms
NLDN Time (UT)		23:42:47.542	...	No NLDN Report

Network Inter-comparison



Video Camera Studies

Strengths:

- Know direction very well, but poorer at distance
- Gets natural first strokes, and most subsequent strokes
- Can obtain data from a large area on a single day
- Can be used to classify lightning type

Weaknesses:

- May miss some subsequent strokes, depending on camera frame rate
- Should be accompanied by E-field measurements
- Cannot directly measure peak current or polarity
- Hampered by rain/visibility

Video Camera Studies

The following two slides contain example results obtained in Texas and Arizona (USA) (work by Krider et al., 2003 and 2004 – manuscript in preparation)

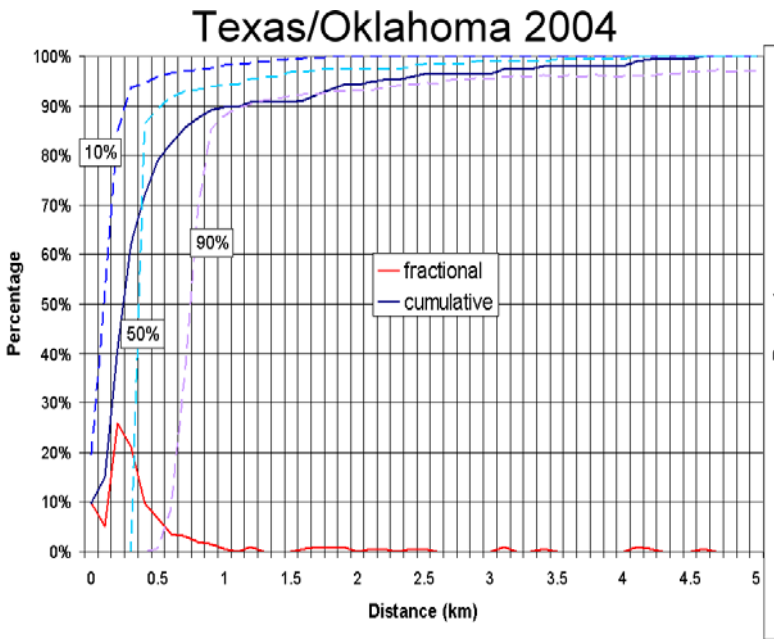
NLDN Video Detection Efficiency Summary

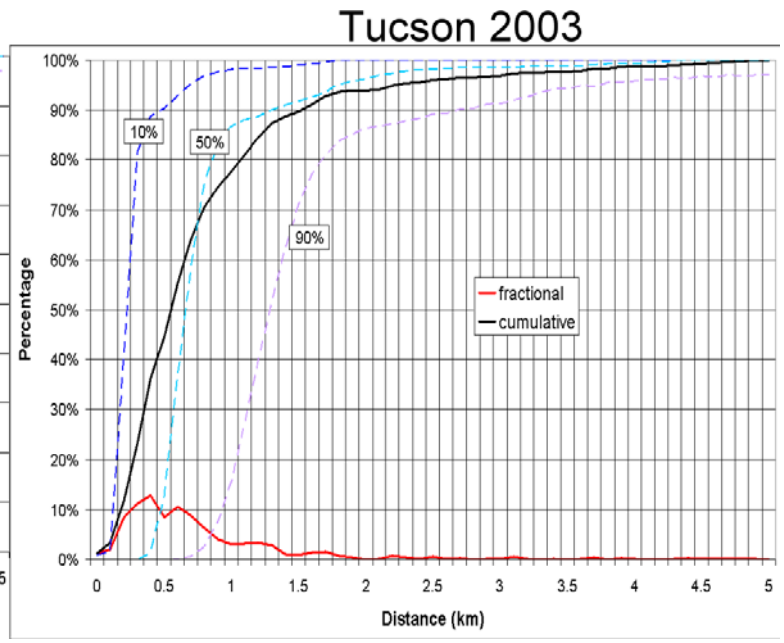
Data Set	Number of Video Flashes	Number of Detected Video Flashes	Flash DE	Number of Video Strokes	Number of Detected Video Strokes	Stroke DE	1st Stroke Average Negative Ip (kA)	Video Multiplicity	NLDN Multiplicity
Tx_Ok_03	59	48	%81.4	126	95	%75.4	14.3	2.14	1.98
Tucson_03	671	636	%94.8	2290	1776	%77.6	19.3	3.41	2.80
Tx_Ok_04	308	291	%94.5	756	661	%87.4	20.6	2.46	2.27
Tucson_04	426	388	%91.1	1330	970	%72.9	20.9	3.12	2.5

Note: The low flash detection efficiency in Texas in 2003 (Tx_Ok_03) was a small dataset derived from “weak” storms (low average peak current and multiplicity, as idicated in the table)

NLDN Video Location Accuracy Statistics

(location error for subsequent strokes in existing channels)





Median location difference = 300m

Median random error ~ 212m

Median location difference = 600m

Median random error ~ 424m

Network Inter-comparison Studies

Strengths:

- **Can evaluate large amounts of data over a large area**
- **Can study relative network performance as a function of time and location**
- **Can compare lightning parameters and related distributions (peak current, polarity, multiplicity, etc.)**

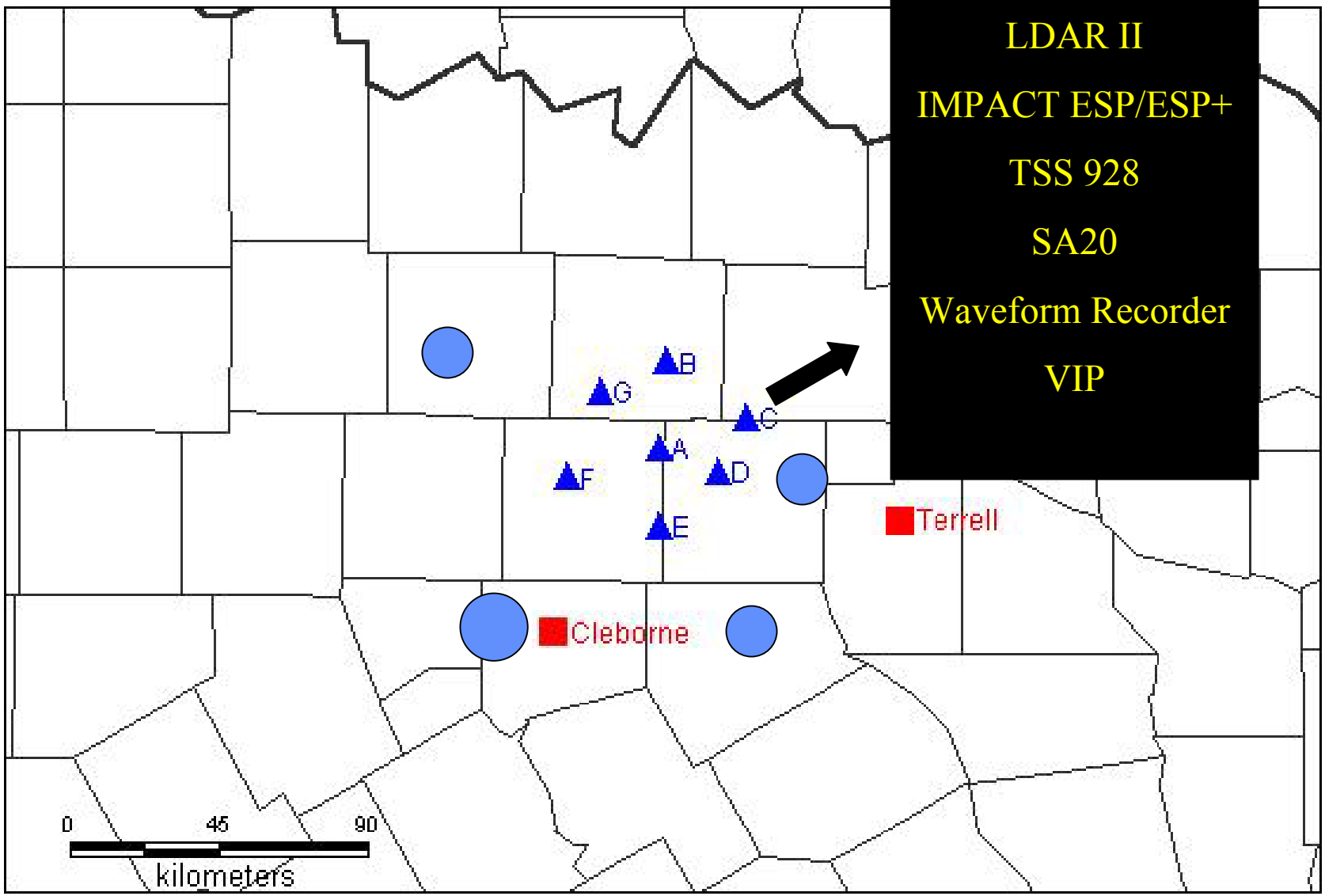
Weaknesses:

- **Need to know the performance of one of the networks**
- **Comparisons are relative, not absolute**

Network Inter-comparison Studies

The following five slides demonstrate assessment of low-frequency-based cloud flash detection efficiency, referenced to a high-resolution VHF Time-of-arrival Total Lightning Network (LDAR II) in Dallas, Texas (USA).

DFW Research Network



Plano Site:

LDAR II

IMPACT ESP/ESP+

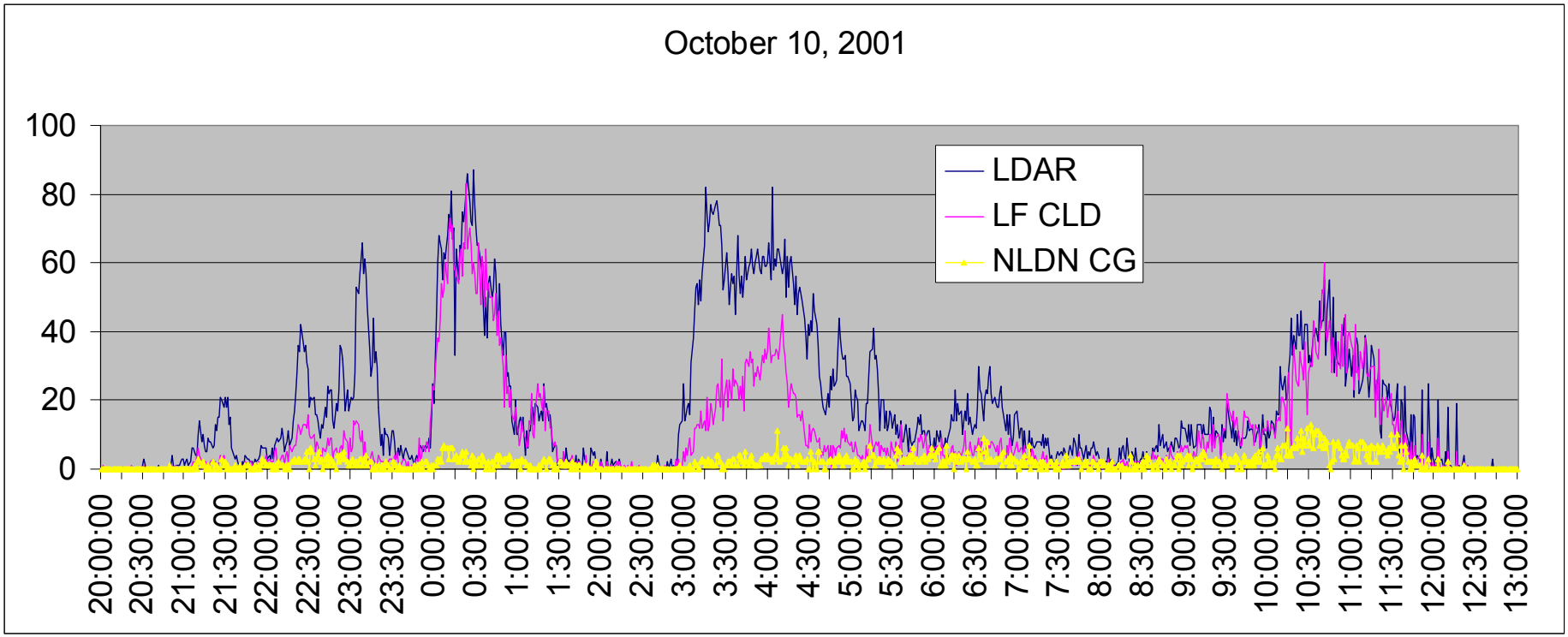
TSS 928

SA20

Waveform Recorder

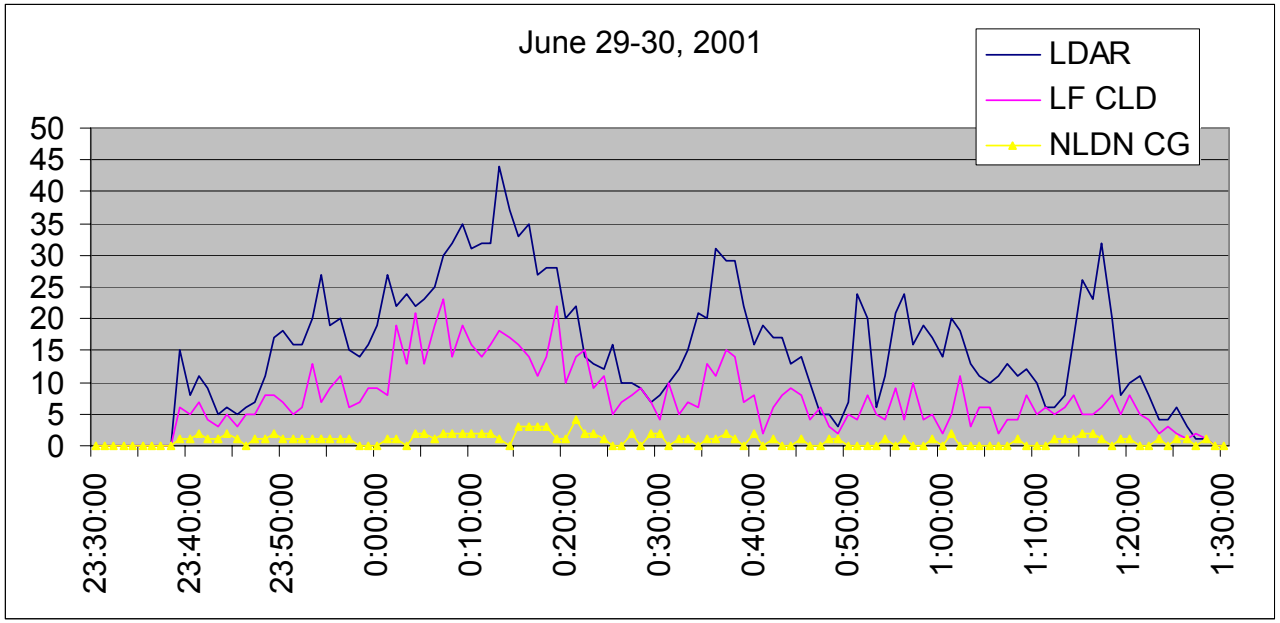
VIP

Cloud Lightning Rates: Various supercells

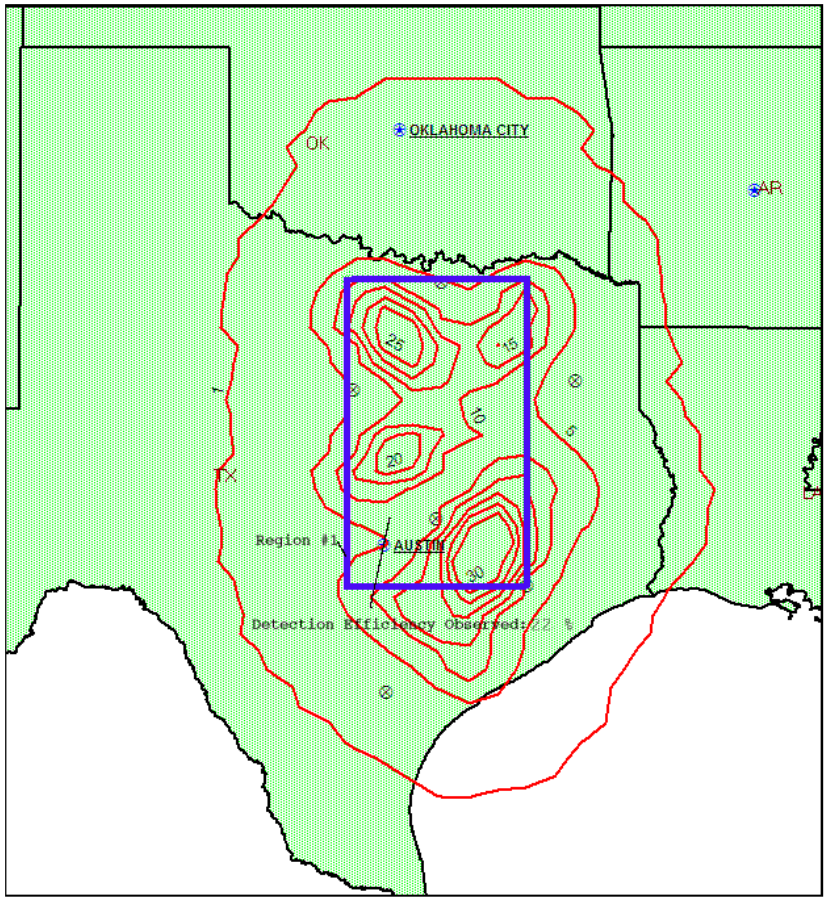


The higher performance periods are when the storms are closer to the heart of the network

Cloud Lightning Rates: Airmass cells



Modeled Cloud Flash Detection Efficiency:
NLDN-based Test Network – Spring 2004



Quantitative Determination of NLDN Cloud Flash Detection Efficiency (Near Dallas, Tx)

Date	LDAR Flashes	NLDN CLD Flashes	NLDN CG Flashes	Small Positive Flashes	IC/CG Ratio	LF CLD DE - small pos as CLD	Modeled CLD DE
5/1/04	537	50	128	22	4.1	16.7	15-25
5/13/04	58	9	19	0	2.1	23.1	>25
5/1/04	122	27	39	8	2.9	38.5	>25
5/1/04	381	72	135	29	2.6	36.7	>25

- Steps:
  - Remove all LF CLD events associated with CG (1 sec)
  - Determine LDAR flash initiation points
  - Remove all except one event LF CLD event per LDAR initiation point (1 sec)
  - Move small positives (< 10kA) into LF CLD category
  - Compute statistics

Network Modeling Studies

Strengths:

- **Can evaluate large amounts of data over a large area**
- **Can study relative network performance as a function of time and location**
- **Can relate lightning parameters (peak current, multiplicity, etc.) to detection efficiency**

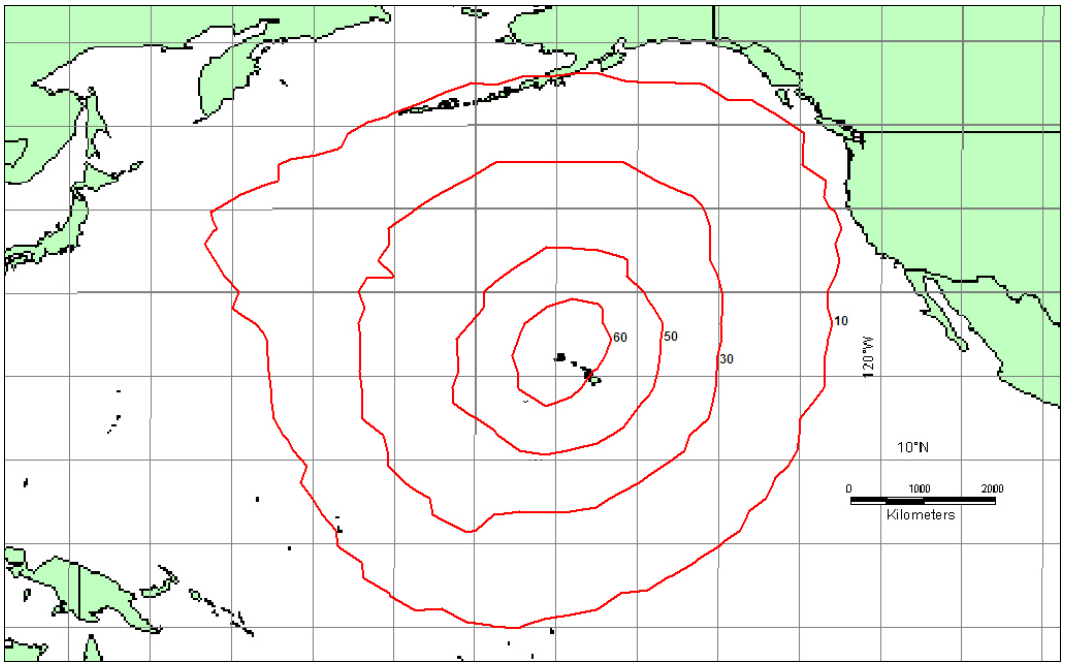
Weaknesses:

- **Analysis is model-based, and dependent on the accuracy of specific assumptions**

Performance Modeling: Detection Efficiency

A detection efficiency (DE) model is used to calculate the probability of the network detecting a lightning discharge, and typically represents this probability as a set of DE “contours”

The DE model computes estimates of the DE on a grid over the area of network coverage. For each grid element, the model generates specific values of peak current and computes the signal strength that should arrive at each sensor in the network using a signal propagation model. The DE model then relates the computed signal strength at each sensor to that sensor's detection efficiency, and this produces a probability that the stroke will be detected by that sensor. Assuming that these sensor probabilities are all independent, the probability of detection by the network can be computed. This process is repeated over the entire range of peak currents at each grid point, and an overall estimate of the network detection efficiency is produced.

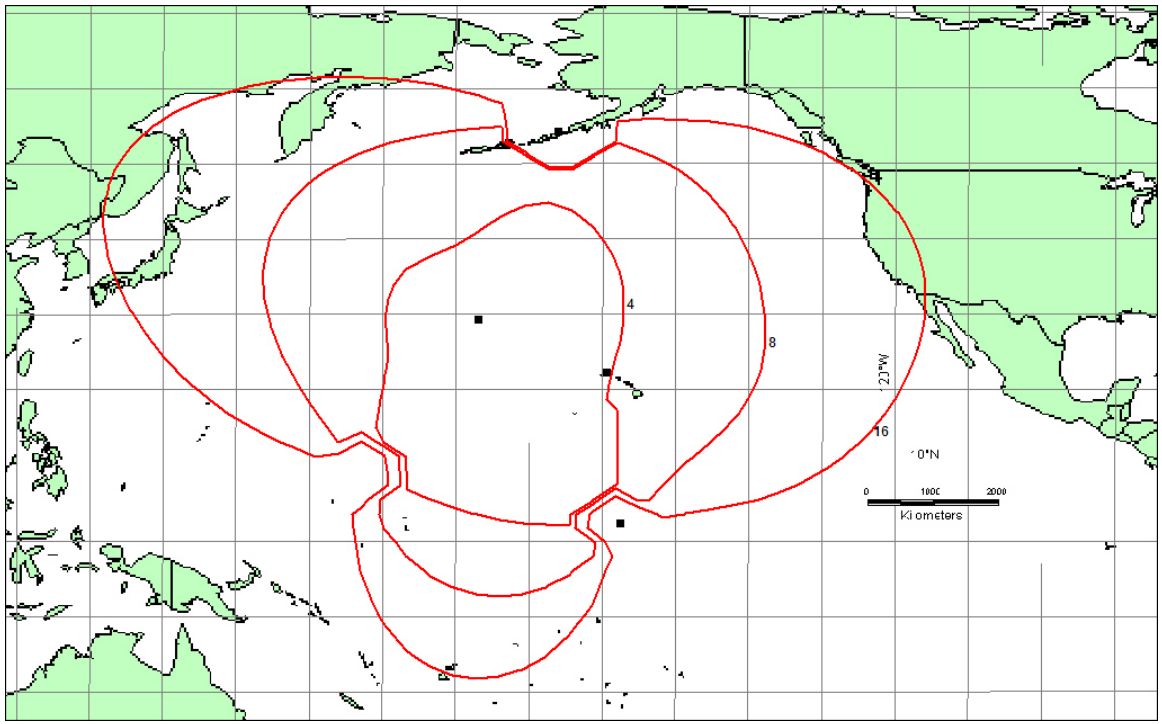


PacNet – Planned Configuration (nighttime performance)

Performance Modeling: Location Accuracy

A location accuracy model is used to calculate the error ellipse (or "confidence region") that characterizes the location accuracy for an individual discharge, and typically represents this accuracy as a set of LA “contours”

In practice, the Vaisala location accuracy model computes the semi-major axis of the error ellipse at center points on a grid over the area of network coverage. The locations and types of sensors and the average angle and/or timing errors must be specified. The model output is a contour map

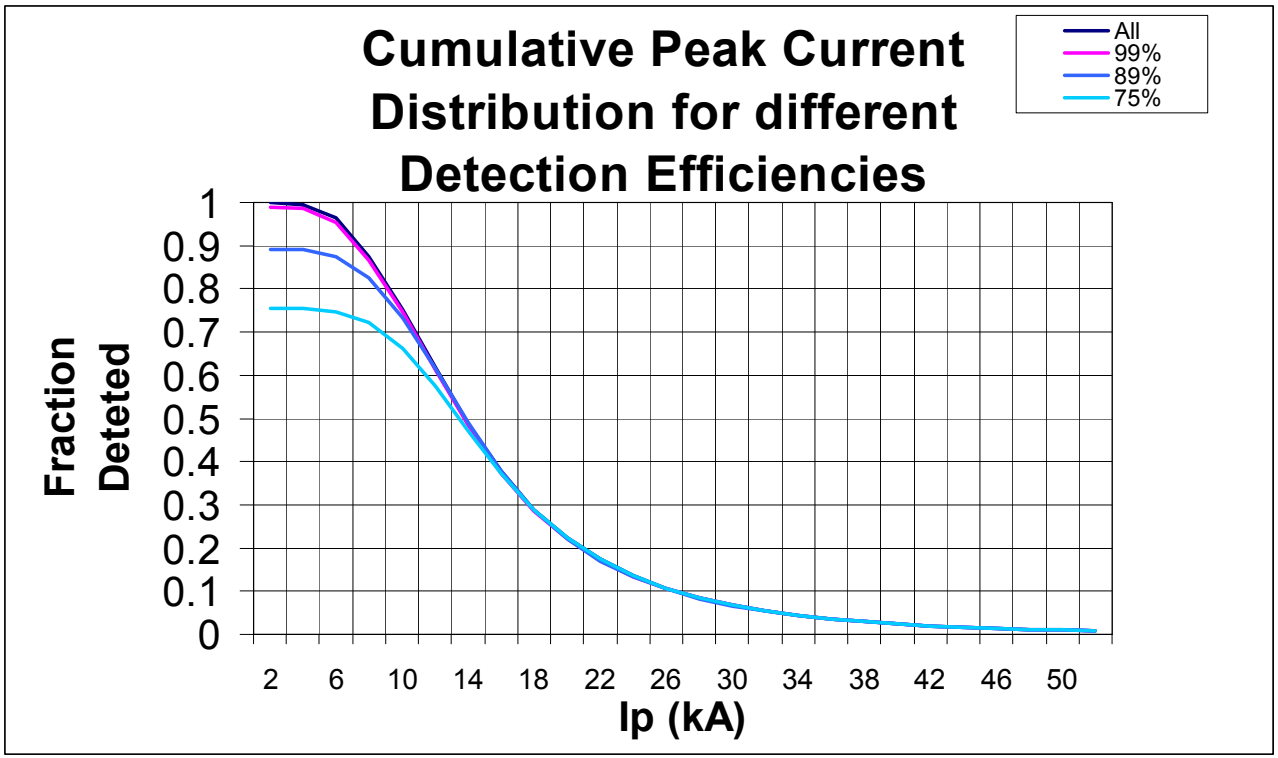


PacNet – Planned Configuration

Effect of DE on Peak Current Distribution: scaled based on Relative DE

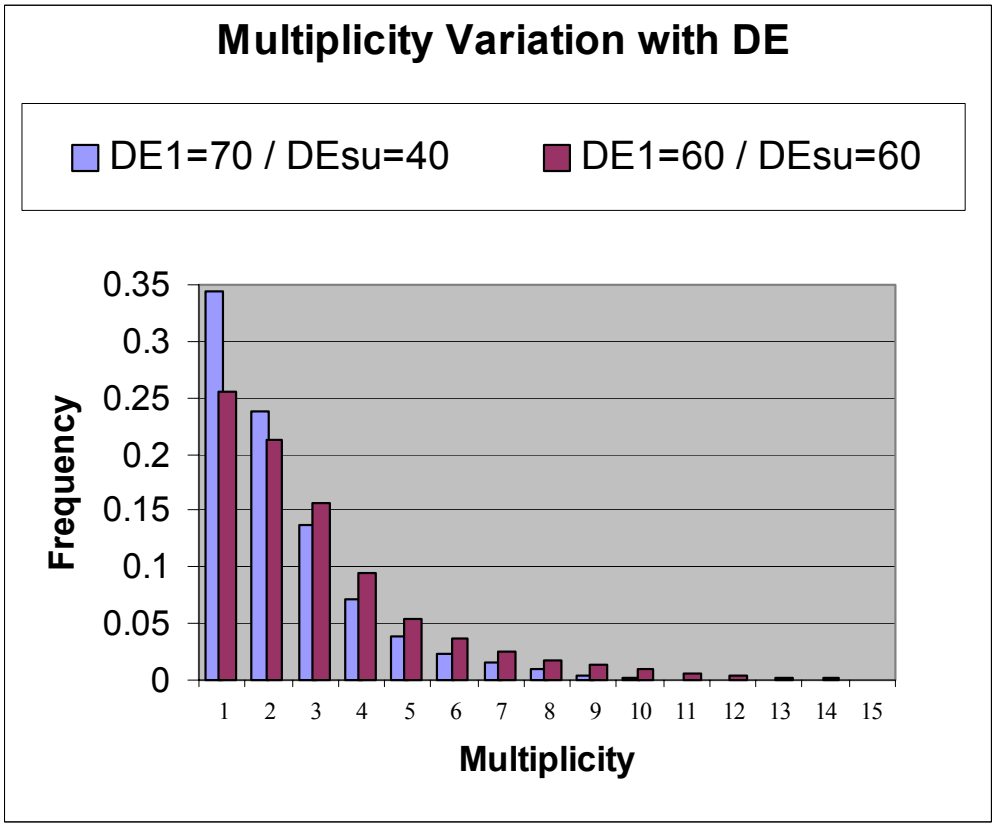
Lower DE curves show a clear loss of low peak current events

All curves "line up" for peak currents above 16 kA



Effect of DE on Estimated Multiplicity Histogram

DE1/ DEs	Flash DE (%)	1-Stroke (%)	Ave. Mult.
100/ 100	100	17	4.5
70/40	89	34	2.4
60/60	89	26	3.1



Selected papers on Network Evaluation/Validation:

Rocket Triggered Lightning Validation

An Evaluation of the performance characteristics of the NLDN using triggered lightning, J. Jerauld, V.A. Rakov, M.A. Uman, K.J. Rambo, D.M. Jordan, K.L. Cummins, J.A.Cramer, 18th International Lightning Detection Conference, 7 to 9 June 2004 Helsinki, Finland

Tower Lightning Validation

Evaluation of lightning location data employing measurements of direct strikes to a radio tower, G. Diendorfer, W. Hadrian, F. Hofbauer, M. Mair, W. Schulz, *CIGRE SC33 Meeting,* September, 2002, Paris, France

Video Validation

A Portable PC-based system for making optical and electromagnetic measurements of lightning, N.G. Parker, N. G. and E. P. Krider, *J. Appl. Met.*, *42*, 739-751, 2003.

NLDN Performance in Arizona, Kenneth E. Kehoe and E. Philip Krider,18th International Lightning Detection Conference, 7 to 9 June 2004 Helsinki, Finland

Performance evaluation of the National Lightning Detection Network in the vicinity of Albany, New York: Part I: Detection efficiency, V.P. Idone, D.A. Davis, P.K. Moore, Y. Wang, R.W. Henderson, M. Ries, and P.F. Jamason, *J. Geophys. Res.*, 1998

Analysis of mono-channel multiple-CG flashes: a means to estimate location efficiency of a lightning detection network, G. Berger, 18th International Lightning Detection Conference, 7 to 9 June 2004 Helsinki, Finland

Network Inter-comparison

On the estimation of the stroke detection efficiency by comparison of adjacent llightning location systems, M. Rubinstein, International Conference on Lightning Protection, 1994, Budapest, Hungary.

Accuracy of the NLDN real-time data service at Cape Canaveral, Florida, M.W. Maier and M.B. Wilson, *1996 Intl. Lightning Detection Conf.*, Nov. 6-8, 1996, Tucson, AZ, USA

Modeling

On the determination of the flash detection efficiency of lightning location systems given their stroke detection efficiency, M. Rubinstein, *EMC Conference Proceedings*, 1995, Zurich.

Detection efficiency and site errors of lightning location systems, W. Schulz and G. Diendorfer, 1996 International Lightning Detection Conference, November 6 – 7, 1996, Tucson, AZ

On the relationship between lightning detection network performance and measured lightning parameters, K. L. Cummins and E. A. Bardo, 1st International Conference on Lightning Physics and Effects, November 2004, Belo Horizonte – Brazil

A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network, K. L. Cummins, M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer *J. Geophys. Res.*, vol. 103, pp. 9035-9044, 1998.